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1 METHOD AND CIRCUIT ARRANGEMENT FOR DETERMINING A QUALITY
2 LEVEL OF PHASE SIGNALS

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4 Background Information

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6 The present invention relates to a method and a circuit arrangement for
7 determining a quality level of phase signals, in particular in the detection of a
8 motion or an angle of rotation or a torque on axes or shafts, according to the
9 definition of the species of the main claim.

10
11 For example, to detect the torque acting on a steering wheel axis of a motor
12 vehicle while the steering wheel rotates, very small angular changes must be
13 measured in both directions of rotation of the steering wheel. It is possible to use
14 incremental angle sensors in this case that assign a measured phase value to an
15 angular position based on the evaluation of signals that are optical, magnetic or
16 that are produced in any other way, e.g., by the rotation, and that are detected
17 using suitable means. To increase the unambiguous range, it is possible to look
18 at a further measurement channel with a different phase slope. A plurality of
19 measured phase values is therefore obtained in this case, from which the
20 quantity to be measured, such as the angle of rotation, an angular difference or
21 the distance from a target, is to be determined.

22
23 When more than two phase signals are involved, a method described in
24 publication DE 101 42 449 A1, for example, is used to evaluate measured phase
25 values of this type. In that method, a highly exact, robust and unambiguous
26 measured phase or angle value is produced from a number N of multivalued,
27 disturbed phase signals. To accomplish this, the measured phase values are
28 mathematically transformed using a linear transformation method, among other
29 things, and evaluated with a specified weighting.

1 The method is used, e.g., with an optical angle sensor, in the case of which N
2 parallel tracks are created on a cylinder. Located on each of the N tracks
3 ($i=1\dots N$) are n_i periods of a phase information that, in the optical case, for
4 example, is represented by n_i periods of light-dark transitions. Other sensor
5 principles, e.g., magnetic or capacitive, are also possible in this case. The tracks
6 of the sensor can also be created on a plane instead of a cylinder, e.g., in the
7 case of a path sensor.

8

9 It is also known, from publication DE 195 06 938 A1, that the phase signals can
10 be evaluated via the single or multiple application of a classical or modified
11 vernier principle.

12

13 To determine an angular difference, it is furthermore also known from publication
14 DE 101 42 448 A1 that the measured phase values are summed in a weighted
15 manner and, from this sum, the whole-number portion and the non-whole number
16 portion are determined. The non-whole number portion is proportional to the
17 angular difference between two groups of tracks of an incremental-value
18 indicator on a shaft. The torque acting on the shaft can therefore be determined
19 via multiplication with the spring rate of a torsion bar installed between the
20 groups of tracks.

21

22 It is also known per se from publication DE 100 34 733 A1 that a specified offset
23 value is added to the measured phase value in an initialization phase and, in
24 turn, as a result, the offset value is compensated. An iterative approximation
25 method carried out to perform offset compensation of two orthogonal sensor
26 signals is also known per se from publication DE 199 15 968 A1.

27

28 The method according to the general class can be used, for example, with a
29 corresponding sensor arrangement—as described in publication DE 101 42 448
30 A1 above—on the steering shaft of a vehicle as a “torque angle sensor” (TAS)
31 that simultaneously transmits the steering angle and steering torque.

1 Advantages of the Invention

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3 With the method according to the general class mentioned initially for detecting
4 the angle of rotation and/or the torque on rotating mechanical components,
5 measured phase values can be evaluated by scanning at least one phase sensor
6 on the rotating component using a sensor assigned to it. According to the present
7 invention, a determination of the quality of the phase signals is advantageously
8 carried out in this manner: once the measured phase values have been
9 transformed with a specified matrix, a vector and the result of a quantization
10 operation regarding the vector are produced. Subsequently, once a
11 transformation has been carried out with a further matrix, a further vector is
12 produced from the difference between the vector and the result of the
13 quantization operation. The absolute value of the minimum is calculated based
14 on the components of the other vector, and the quality level is derived therefrom.
15 The quality level can be determined in a particularly advantageous manner
16 according to the following relationship:

17 $R \cdot e_{\max} = \min_{j=1 \dots n_x} |D_j \pm x_j \cdot C_j|,$

18 whereby the variables C_j and D_j are coefficients that are derivable from the phase
19 signals. Application of coefficients C_j and D_j , and the transformation of the vector
20 with the further matrix can also be easily combined into one method step.

21

22 The method according to the present invention can be realized in an
23 advantageous manner with a circuit arrangement composed of an electronic
24 circuit and that includes a linear mapping module for processing the phase
25 signals, and a quantization module. Using a further linear mapping module,
26 the other vector can be produced from the difference of the vector at the output
27 of the first linear mapping module and the result of the quantization operation at
28 the output of the quantization module, it being possible to apply the coefficients
29 to said other vector in further modules.

30

1 With the method according to the present invention and the circuit arrangement,
2 it is therefore possible, in an advantageous manner, to determine a scalar level
3 of quality for evaluating the interrelationship between the individual measured
4 phase values. With the aid of this level, it is then possible to detect interferences
5 and erroneous measurements by the sensor system. The present invention
6 therefore makes it possible to monitor the sensor system in entirety, since it has
7 not been previously possible to evaluate the entire system in this manner. For
8 example, if the position of the sensor head is slanted relative to the sensor tracks
9 due to a "tilt angle", the level of quality is reduced considerably. The present
10 invention furthermore describes a method and a circuit arrangement for
11 determining the level of quality with a small outlay for software and/or hardware
12 in an electronic circuit, since the calculation of the absolute angular values is
13 initially not required to calculate the level of quality.

14

15 Drawing

16

17 An exemplary embodiment of a circuit arrangement for carrying out the method
18 according to the present invention is explained with reference to the drawing.

19

20 Figure 1 shows a schematic view of a circuit arrangement for detecting the
21 angle of rotation of an axis or shaft by evaluating phase signals, and the
22 arrangement for determining the level of quality, and

23

24 Figure 2 shows a depiction of the phase signals after a transformation and
25 quantization in a two-dimensional space.

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27 Detailed Description of the Embodiment

28

29 Figure 1 shows a block diagram of a circuit arrangement for detecting the angle
30 of rotation of an axis or shaft by evaluating phase signals α , which are measured
31 on an axis of a rotating component, for example, the angle of rotation Φ and

1 angular difference of which are determinable by using an appropriate sensor
 2 arrangement. An arrangement of this type is known in principle from the
 3 publication DE 101 42 448 A1 mentioned as the related art in the introduction to
 4 the description, above. It is known from publication DE 101 42 449 A1, which is
 5 also mentioned in the introduction to the description, that the following equation
 6 applies for phase signals α_i in the case of an angle sensor with N phase signals:

7

$$\begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \vdots \\ \alpha_N \end{pmatrix} = \text{mod}_{2\pi} \left[\Phi \cdot \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ \vdots \\ n_N \end{pmatrix} \right] \quad (1)$$

8

9 The quantity Φ in this case is the absolute angle being searched for in the
 10 measurement task, whereby the same relationships also apply for a linear path
 11 sensor. Ideal measured values are a prerequisite in this case, i.e., there are
 12 basically no measurement errors. The description of the method according to the
 13 present invention is then carried out based on a four-dimensional phase
 14 evaluation ($N=4$) of the signals from optical signal sensors. From this, the angular
 15 position Φ_m and, if applicable, the torque of the shaft or axis, can be determined
 16 using the further modules.

17

18 Shown in detail in Figure 1 is a linear mapping module M1 for transforming the
 19 phase signals $\underline{\alpha}$ using a matrix M_1 into a vector \underline{T} , and a quantization module V
 20 for producing a quantization operation \underline{V} . Following this is a further linear
 21 mapping module M3 for performing a transformation with a matrix M_3 , followed by
 22 an operation—which is also known from the related art—with a mod 2^{16} module
 23 with consideration for the output signal of a weighting module W for phase
 24 signals $\underline{\alpha}$ around angular position Φ .

25

1 The starting point for calculating the level of quality R according to the present
 2 invention are the phase values themselves or a determination according to
 3 equation (2) below from the difference \underline{t} between vectors \underline{T} and \underline{V} , which are
 4 available, in principle, as intermediate values of the multidimensional phase
 5 evaluation according to the related art DE 101 42 449 A1 with the circuit
 6 arrangements that are common here.

7

8 $\underline{t} = \underline{T} - \underline{V} = \underline{T} - \text{quant}(\underline{T}) \quad (2)$

9

10 This N-1 dimensional difference \underline{t} is depicted in a vector \underline{X} with the aid of a matrix
 11 M4 according to Figure 1 in a linear mapping module M4:

12

13 $\underline{X} = \underline{M}_4 \cdot \underline{t} \quad (3)$

14

15 Matrix M4 is composed of

16

17 $n_x = \binom{N}{N-2} = \frac{N!}{2 \cdot (N-2)!} \quad (4)$

18

19 rows. The components x_j of vector \underline{X} are subsequently multiplied by coefficients
 20 C_j in a module C. A further n_x coefficients D_j are then added or subtracted to or
 21 from the result. Using the $2n_x$ values obtained in this manner, the absolute value
 22 of the minimum is subsequently calculated in a module R. This minimum has the
 23 value

24

25 $R \cdot e_{\max} = \min_{j=1 \dots n_x} |D_j \pm x_j \cdot C_j| \quad (5)$

26

27 The value e_{\max} is the error that is permissible simultaneously in all N phase
 28 values; e_{\max} depends on the dimension and the special selection of period
 29 numbers n_j . The calculation steps for the quantities mentioned above are shown,
 30 in principle, in the signal flow chart in Figure 1 for N=4 dimensions, for example.

1 The circuit arrangement for other dimensions N is basically identical, and only the
 2 stated number of signal lines changes.

3

4 Based on a number with $N = 3$ phase signals as an example, the following values
 5 are assumed, for instance: $n_1=3$, $n_2=4$, and $n_3=5$. The values from equation (2)
 6 are used as the starting point. In this case, matrices \underline{M}_1 and \underline{M}_4 are:

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$$\underline{M}_1 = \begin{pmatrix} 1 & -2 & 1 \\ -1 & -1 & 2 \end{pmatrix} \quad \underline{M}_4 = \begin{pmatrix} -2 & 1 \\ -1 & 2 \\ 2 & 1 \end{pmatrix}$$

8

9 and coefficients C_j and D_j , each with $j = 1 \dots 3$, then have the values:
 10

$$C_1 = \frac{1}{7}, \quad C_2 = \frac{1}{8}, \quad C_3 = \frac{1}{9}, \quad D_1 = \frac{1}{7}, \quad D_2 = \frac{1}{8}, \quad D_3 = \frac{1}{6}$$

11

12 For ideal phase signals according to equation (1), $R = 1$ and
 13

$$R \cdot e_{\max} = 45^\circ$$

15

16 apply. If all phase signals α_i are shifted by 180° as an inverse pattern, a level of
 17 quality of $R = 0$ results.
 18

19 The level of quality R calculated with the methods described above indicates how
 20 much noise or which measurement error, starting with the current measured
 21 phase value, can still be permitted while guaranteeing the desired level of
 22 functionality. An example with $N = 3$ dimensions is shown in Figure 2. In this
 23 example, after a transformation into a two-dimensional t-space, the range limits
 24 BG for the measured phase values in the t space are shown as vectors \underline{t} . The
 25 possible locations of the noise for a correct result are enclosed in the area RB.

1 In this case, the noise is typically based on the value e_{\max} . This means that, given
2 ideal phase values according to relationship (1), $R = 1$ applies and the current
3 measured value is therefore located in the starting point of vector \underline{t} . If the current
4 measured value is located exactly on an area limit BG of quantization unit V
5 according to Figure 1, the level of quality R assumes its minimum value $R = 0$.

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